primarily during the project period, but also in the period following. Readership is primarily USA-based, but the blog has a global audience; views have come from dozens of countries.

Evidence that the blog format facilitated discussion is seen in the 54 total comments on project posts, primarily exchanges between project participants and post authors. In particular, the format facilitated discussion of Ellis' use of ideas drawn from outside his own discipline, as seen in a particular exchange with humanists who critiqued his conceptualization of culture.

Finally, we have subjective accounts of the opportunity for intellectual growth the project offered its participants (a selection is found in Box 2). These show the value of the project for scholars across the disciplinary spectrum. And Ellis himself attested to the success of the project in generating useful responses to his paper, stating that it 'vastly deepened my understanding not only of the broader implications of my work, but more importantly made me think more deeply about a number of elements of my theory, helping me to move forward in important new directions. This is a process I would recommend to any scientist aiming to deepen their theoretical world.'

To conclude, because the Anthropocene Biosphere Project was not designed as a study, our evaluation of it is informal. But reflecting on our experience does suggest ways future projects might be assessed more formally. A more comprehensive assessment could include pre- and post-project surveys of participants, in order to judge any change in their understanding of the material specifically, and in their understanding of and appreciation for work from other disciplines more generally. And it might include pre- and post-project surveys of a focus group, for example, students in a relevant class, in order to judge any change in their comprehension of the material presented, and of its use of interdisciplinary sources. Finally, it could incorporate directly into the blog an analytics tool to measure project reach more precisely, as well as an assessment protocol, for example, a survey for readers.

Acknowledgments

The Anthropocene Biosphere Project took place while the lead author was a Fellow of the OU Humanities Forum, which provided financial and logistical support for project. We thank TREE editor Paul Craze and an anonymous reviewer for their insightful comments.

Resources

[i] https://dx.doi.org/10.15763/DBS.anthbiosphere.001

[1]Department of Philosophy, University of Oklahoma, Norman, OK, USA
[2]Department of Sociology, University of Oklahoma, Norman, OK, USA
[3]Department of Geography, University of Oklahoma, Norman, OK, USA
[4]Oklahoma Biological Survey, University of Oklahoma, Norman, OK, USA
[5]Department of Biology, University of Oklahoma, Norman, OK, USA
[6]Department of Anthropology, University of Oklahoma, Norman, OK, USA
[7]Department of History of Science, University of Oklahoma, Norman, OK, USA
[8]Department of Geology, University of Oklahoma, Norman, OK, USA
[9]Department of English, University of Oklahoma, Norman, OK, USA

*Correspondence: ztrachtenberg@ou.edu (Z.M. Trachtenberg).

http://dx.doi.org/10.1016/j.tree.2016.10.018

References

1. Steffen, W. *et al.* (2011) The Anthropocene: conceptual and historical perspectives. *Phil. Trans. R. Soc. A* 369, 842–867
2. Harden, C.P. *et al.* (2014) Understanding human-landscape interactions in the 'Anthropocene'. *Environ. Manage.* 53, 4–13
3. Ellis, E.C. (2015) Ecology in an anthropogenic biosphere. *Ecol. Monogr.* 85, 287–331
4. Rossini, F.A. and Porter, A.L. (1979) Frameworks for integrating interdisciplinary research. *Res. Policy* 8, 70–79
5. Goring, S.J. *et al.* (2014) Improving the culture of interdisciplinary collaboration in ecology by expanding measures of success. *Front. Ecol. Environ.* 12, 39–47
6. Walker, J. (2006) Blogging from inside the ivory tower. In *Uses of Blogs* (Bruns, A. and Jacobs, J., eds), pp. 127–138, Peter Lang
7. Weller, M. (2011) *The Digital Scholar: How Technology Is Transforming Scholarly Practice,* Bloomsbury
8. Harris, F. and Lyon, F. (2013) Transdisciplinary environmental research: building trust across professional cultures. *Environ. Sci. Policy* 31, 109–119
9. MacMynowski, D.P. (2007) Pausing at the brink of interdisciplinarity: power and knowledge at the meeting of social and biophysical science. *Ecol. Soc.* 12, 20
10. Miller, T.R. *et al.* (2008) Epistemological pluralism: reorganizing interdisciplinary research. *Ecol. Soc.* 13, 46
11. Andrade, K. *et al.* (2014) Finding your way in the interdisciplinary forest: notes on educating future conservation practitioners. *Biodivers. Conserv.* 23, 3405–3423

Science & Society

The Rise of Invasive Species Denialism

James C. Russell[1,2,@,*] and Tim M. Blackburn[3,4,@]

Scientific consensus on the negative impacts of invasive alien species (IAS) is increasingly being challenged. Whereas informed scepticism of impacts is important, science denialism is counterproductive. Such denialism arises when uncertainty on impacts is confounded by differences in values. Debates on impacts must take into account both the evidence presented and motivations.

IAS are defined by their negative impact, for which there is such an overwhelming body of global evidence [1] that IAS now rank as one of the major challenges to biodiversity conservation of our time. Reporting on invasive species and their threats is increasingly found in the mainstream media and literature. At first this coverage reflected the scientific orthodoxy that IAS have negative biodiversity, social, and economic impacts. More recently, however, many of these stories, sometimes in high-profile media outlets (e.g., *The Economist*[i], *New Scientist*[ii], *The New York Times*[iii]) or books[iv,v], have challenged the existing scientific consensus on IAS. In some cases the scientific evidence and consensus on the impact of IAS have been misinterpreted and misrepresented. Although many of these challenges have come from laypeople, scientific journal opinion pieces [2] and

Box 1. Arguments Against IAS

Opposition to policy and action on invasive species has recently emerged, often attempting to reframe the debate [11]. Impact has been narrowly defined only as extinction, when that is actually an acute, extreme end point of a wide range of more subtle and chronic impacts attributable to IAS [12]. Although IAS might increase local and regional species richness, the extinctions for which they are responsible cause global species richness to be reduced much faster than it is recovered.

Some opponents argue that the debate should be about species effects exceeding a damage threshold rather than species origin. However, the definition of an IAS itself depends on exceeding a damage threshold, while recognising that impacts [13], and the ethical duties of humans [14], differ between native and alien species. Some authors have suggested that the future of environmental management should involve acceptance of alien species in 'novel ecosystems', rationalising defeat or conciliation as the morally acceptable course of action [15]. Nevertheless, although in many cases it might not be possible to reverse the effects of IAS, this still does not ethically legitimise capitulation as a course of action [14] any more than it would for climate change or deforestation.

books [3] written by ecologists have also attempted to reframe, downplay, or even deny the role of IAS in global change (Box 1). Here we outline how disagreement over the impacts of IAS can arise from both the interpretation of evidence and underlying motivating values. Where evidence is disregarded, or motivations are disingenuous, arguments against IAS take the form of science denialism. We hope to inform ecologists how better to identify invasive species denialism and engage in progressive arguments to further invasion biology.

Defining Impacts

The IUCN defines an IAS as 'introduced by man [*sic*] into places out of their natural range of distribution, where they become established and disperse, *generating a negative impact*' (our emphasis). Determining the negative impact of IAS depends on both objective scientific evidence and subjective value definitions of impact. Disagreement over impacts, and hence the classification of an alien species as an IAS, can thus arise from either differing interpretations of the evidence or underlying values. However, it might not always be clear which of these is the primary motivator for dissent. Further disagreement can arise from the use of other definitions of IAS, which do not always include an explicit statement about impact, or determining that a species might be invasive because it has a wide distribution without observed negative impacts or has not yet spread widely enough to generate impacts. In these cases doubt can exist over the current evidence for perceived negative impacts, and it necessarily exists over negative impacts that are yet to occur. This can further cloud the legitimacy of distinguishing invasive from other alien species.

Scientific evidence always contains an element of uncertainty, which will play a constant role in valid research and debate on the impacts of IAS. Even if IAS are in the minority among alien species, these uncertainties indicate that a precautionary approach to all alien species is warranted [4]. However, the additional component of a value definition of the negative impacts of IAS can create disagreement outside the scope of science of what does and does not constitute an IAS. Such differences in values can be capitalised on by those who might want to challenge the case for the impact of IAS for a variety of motivations. In some cases the rejection of scientific evidence of the negative impacts of IAS takes the form of a type of science denialism.

Debate and Denialism

Science denialism is the rejection of undisputed scientific facts. Denialism differs from scientific debate, which arises from the uncertainty implicit in the scientific method. Ideas that survive and become accepted parts of the body of scientific knowledge do so because they are yet to be falsified or at least provide the most likely explanation that is consistent with the existing body of scientific knowledge. The scientific process relies on informed scepticism and challenges by bold scientists to the prevailing consensus (e.g., the heliocentric model, Darwinian evolution, plate tectonics), but these challenges succeed because the new ideas provide a better or more parsimonious explanation of observations. By contrast, denialism attempts to manufacture uncertainty in the scientific consensus on an otherwise undisputed topic (e.g., the risks of tobacco smoking or immunisation, the causes of AIDS or climate change, evidence for evolution), exploiting the fact that all scientific knowledge contains an element of uncertainty. This can lead to journalists presenting consensus and contrarian alternatives as 'balanced', ignoring the fact that the weight of evidence is heavily in favour of the former and conflating debates about policy responses with debates about the supporting science [5].

Science denialism typically originates from groups with a vested interest in opposition to the scientific consensus and is often characterised by downplaying the scope of a threat. It often arises when science enters the policy arena and policy outcomes threaten to impact the freedoms or behaviours of others. It is therefore probably no coincidence that the original challenges to the orthodoxy of invasion biology came from outside science [6]. Although no formal studies of invasive species denialism exist, research into other domains of denialism finds that deniers typically consistently reject scientific evidence on a range of different topics and that there is a strong correlation with support of free-market ideologies such as *laissez-faire* regulation [7]. Invasion biologists regularly call for increased regulation and restrictions on species transportation, translocation, or trade in response to the current and future threat of invasive species [4]. It is therefore unsurprising that the tenets of invasion biology and policy are rejected in a framework of science denialism. Such invasive species denialism is likely to become even more prominent with the growing efforts to address the

threats posed by IAS and is likely to come from the same types of sectors that oppose climate change in a denial framework.

Moving Forwards

The emergence of the discipline of invasion biology has been productive scientifically [8] but for many reasons has struggled to translate into meaningful action towards IAS remediation or prevention, particularly in nation states on continents where the challenges can be overwhelming [1]. The role of IAS as global change drivers can be uncertain and subjective, critically relying on the definition of impact, but denying evidence of impacts is not helpful to the development of meaningful policy.

Addressing the challenges of IAS and resolving conflict in their management will require the adoption of frameworks from other areas of conservation conflict that invoke appropriate social science and stakeholder processes alongside the natural sciences [9]. Meanwhile, the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) now provides an analogue to the Intergovernmental Panel on Climate Change (IPCC) to address the major challenges facing biodiversity. International meetings such as the Convention on Biological Diversity (CBD) now explicitly include IAS, such as in the 2020 Aichi targets. The EU has recently adopted legislation to deal with the threat from a small number of IAS. Individual governments recognise the need to deal with some IAS and eradication of IAS is increasingly gaining currency as a conservation action [10].

The recent rise in IAS scepticism and denialism is alarming, especially when coming from both popular and scientific quarters, but reflects both scientific uncertainty and underlying motivations and values. Ultimately, this characterises a broader discourse emerging on the role of IAS in global change. Invasion biologists should be prepared to respond to challenges to their evidence and discipline (Box 2). A comparable rise in dissenting voices was also observed in emerging climate change dialogue a decade earlier [7] and in general such vocal, public debates on perceived threats characterise an acknowledgment and mainstreaming of the scope of the problem. There should be a vibrant and robust dialogue on the negative, and potentially any positive, impacts of IAS and on the allocation of resources to remediate their diverse threats. However, such a discussion should be evidence based and not disrupted by appeals to values or denial of the magnitude of the threat. We believe it is imperative that invasion biologists engage constructively and lead on such discussions, reporting the most current scientific evidence available while acknowledging that values also contribute to the definition and management of IAS.

Box 2. Responding to IAS Denialism

For those faced with science denialism, general guidelines on engaging in a public discourse are available [5]. Three broad types of response are recommended: (i) engage the criticisms but shift the debate from questions of scientific fact to questions of policy response; (ii) do not deny scientific uncertainty where it exists as a natural part of scientific advancement, but do not overstate it; and (iii) emphasise evidence where scientific controversy is being manufactured to manipulate policy outcomes (e.g., [16]). Specific responses to some of the commonly levelled criticisms of invasion biology are also available [11].

Scientists should be encouraged to publish opinion pieces on important topics where their extensive knowledge in an area of expertise best places them to communicate complex scientific ideas and evidence to the public or policymakers and, where appropriate, raise scepticism. At times it may even be valuable for scientists to be contrarian where it offers the opportunity validly to challenge scientific paradigms. However, in doing so scientists must be mindful of their own underlying motivations and values, which all people hold, and distinguish scientific evidence from values in their arguments.

Acknowledgments

The authors thank Mick Clout, Julie Lockwood, the Editor, and two anonymous reviewers for feedback on earlier versions of the manuscript. J.C.R. acknowledges CAPES Proposal 235453 funding from the Ministry of Education, Brazil.

Resources

[i] www.economist.com/news/international/21679447-nobody-likes-interloper-invasive-species-are-more-benign-generally and http://www.economist.com/news/leaders/21679471-most-campaigns-against-foreign-plants-and-animals-are-pointless-and-some-are-worse

[ii] www.newscientist.com/article/mg22730372-000-invasive-species-caused-nearly-half-of-extinctions-its-hearsay/

[iii] nytimes.com/2016/03/01/science/invasive-species.html

[iv] Orion, T. (2015) Beyond the War on Invasive Species: A Permaculture Approach to Ecosystem Restoration, Chelsea Green

[v] Pearce, F. (2015) The New Wild: Why Invasive Species Will Be Nature's Salvation, Icon Books

[1]School of Biological Sciences and Department of Statistics, University of Auckland, Auckland, New Zealand
[2]Department of Preventive Veterinary Medicine and Animal Health, School of Veterinary Medicine, University of São Paulo, São Paulo, Brazil
[3]Centre for Biodiversity and Environment Research, Department of Genetics, Evolution, and Environment, University College London, Gower Street, London WC1E 6BT, UK
[4]Institute of Zoology, ZSL, Regent's Park, London NW1 4RY, UK

*Correspondence: j.russell@auckland.ac.nz (J.C. Russell).
@Twitter: @IsldJames; @TimBlackburn66

http://dx.doi.org/10.1016/j.tree.2016.10.012

Trends

Perceived impacts of invasive species depend on both evidence and values.

Evidence for invasive species' impacts is increasingly being challenged.

The motivation for challenging impacts can depend on underlying values.

Invasion biologists should report evidence while acknowledging values.

References

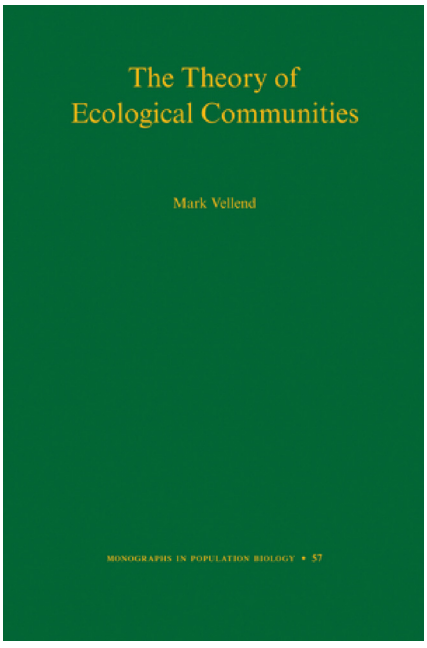
1. Bellard, C. *et al.* (2016) Global patterns in threats to vertebrates by biological invasions. *Proc. R. Soc. B* 283, 20152454
2. Thomas, C.D. (2013) The Anthropocene could raise biological diversity. *Nature* 502, 7
3. Thompson, K. (2014) *Where Do Camels Belong?. The Story and Science of Invasive Species.* Profile Books
4. Essl, F. *et al.* (2011) Socioeconomic legacy yields an invasion debt. *Proc. Natl. Acad. Sci. U.S.A.* 108, 203–207
5. Ceccarelli, L. (2011) Manufactured scientific controversy: science, rhetoric, and public debate. *Rhetoric Public Aff.* 14, 195–228
6. Simberloff, D. (2016) Jacques Tassin: La grande invasion: Qui a peur des especes invasives? *Biol. Invasions* 18, 295–297

7. Lewandowsky, S. *et al.* (2013) NASA faked the Moon landing – therefore, (climate) science is a hoax: an anatomy of the motivated rejection of science. *Psychol. Sci.* 24, 622–633
8. Lowry, E. *et al.* (2012) Biological invasions: a field synopsis, systematic review, and database of the literature. *Ecol. Evol.* 3, 182–196
9. Redpath, S.M. *et al.* (2013) Understanding and managing conservation conflicts. *Trends Ecol. Evol.* 28, 100–109
10. Jones, H.P. *et al.* (2016) Invasive-mammal eradication on islands results in substantial conservation gains. *Proc. Natl. Acad. Sci. U.S.A.* 113, 4033–4038
11. Richardson, D.M. and Ricciardi, A. (2013) Misleading criticisms of invasion science: a field guide. *Divers. Distrib.* 19, 1461–1467
12. Jeschke, J.M. *et al.* (2014) Defining the impact of non-native species. *Conserv. Biol.* 28, 1188–1194
13. Salo, P. *et al.* (2007) Alien predators are more dangerous than native predators to prey populations. *Proc. R. Soc. B* 274, 1237–1243
14. Caro, T. (2013) Anthropocene: keep the guard up. *Nature* 502, 624
15. Carroll, S.P. (2011) Conciliation biology: the eco-evolutionary management of permanently invaded biotic systems. *Evol. Appl.* 4, 184–199
16. Margolis, M. and Shogren, J.F. (2012) Disguised protectionism, global trade rules and alien invasive species. *Environ. Resour. Econ.* 51, 105–118

Book Review

Putting Community Ecology in a Better Order

Madhav P. Thakur[1,2,*]



In 1986, Thomas W. Schoener wrote a thought-provoking book chapter describing ecological communities along five organismal and five environmental axes [1]. It was thought-provoking in the sense that Schoener attempted to unify community ecology using a minimal set of variables at a time when ecologists were doubtful of any unifying principle in community ecology [2]. After three decades of Schoener's chapter, community ecologists are still divided about whether there could be a general theory of community ecology [2,3]. Mark Vellend elegantly attempts to bridge this divide by introducing the theory of high-level processes in ecological communities in his Princeton Population Monograph entitled *The Theory of Ecological Communities*. His theory of ecological communities is largely drawn from the four fundamental principles of population genetics: selection, drift, mutation, and gene flow. He replaces mutation and gene flow by speciation and dispersal respectively, and advocates that the four high-level processes (selection, drift, speciation, and dispersal) are universally present across ecological communities in any environment.

Vellend's book can broadly be divided into two parts: the first part (chapters 1–5) lays a conceptual foundation of high-level and low-level processes and the underlying relations between them. The second part (chapters 7–10) consists of empirical evidence for each of the four high-level processes across a wide variety of ecological communities. One chapter in the book (chapter 6) is dedicated to simulating ecological communities using R programming software. Vellend concludes his book (chapters 11 and 12) with recommendations on how his theory could unify community ecology.

Vellend argues that the patterns observed in ecological communities (e.g., species–area relations, diversity–productivity relations, disturbance–diversity relations, etc.) are a consequence of a plethora of low-level and high-level processes. Low-level processes in ecological communities may range from competition between species in the same trophic group, to predator–prey or host–pathogen interactions, to trait–environment relationships. The structure and function of a given ecological community are likely to be driven by a given set of low-level processes, which often differ among ecological communities (Figure 1). By contrast, Vellend highlights that the four high-level processes are always present in any ecological community, and are fundamental drivers of community structure and function. For instance, speciation and dispersal are the high-level processes which will always play a crucial role in determining the number of species in a community. It is, however, possible that the relative importance

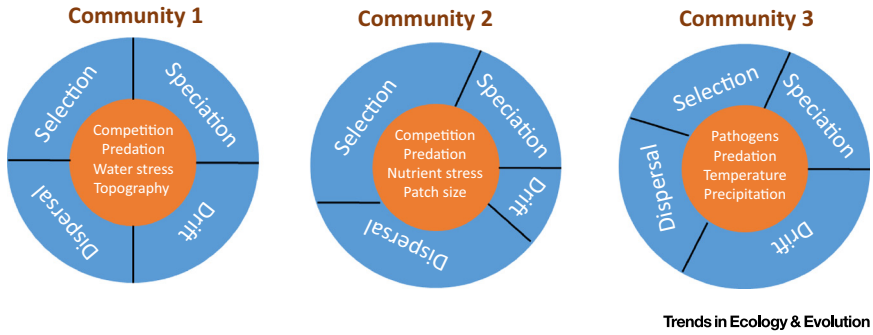


Figure 1. A Conceptual Figure To Depict Vellend's Theory of Ecological Communities. The blue part of the circle represents the four high-level processes and the orange part represents the low-level processes. All three communities in the figure are subject to the four high-level processes; however, the relative roles of these processes can differ among communities. Numerous low-level processes are present in every community, but a given set of low-level processes in one community may not be present in another community.